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RDE COMMAND FIRST APPLICATION (1^{ST} APP) SIMULATION EXPERIMENT FOR FUTURE COMBAT SYSTEMS (FCS) NETWORKED FIRES

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13. ABSTRACT *(Maximum 200 Words)*
The Virtual Distributed Laboratory for Modeling and Simulation (VDLMS) Science and Technology Objective (STO) initiated a First Application (1st App) effort in 2003, to baseline the use of legacy distributed simulations within the U. S. Army Research, Development, and Engineering Command (RDECOM) to support Future Combat Systems (FCS) and Objective Force (OF) experimentation. This baseline provides a threshold in performance and process against which the emerging Modeling Architecture for Technology, Research, and EXperimentation (MATREX), a combined simulation architecture between VDLMS and the Joint Virtual Battlespace (JVB), can be compared. This baseline was defined in terms of the cost, schedule, and performance of the conduct of a full-blown distributed real-time event representing a major portion of an FCS Unit of Action (UA), with sufficient data to conduct meaningful analysis in the context of an exploratory experiment. Networked Fires was the analysis context chosen for this event, due to the critical need for an understanding of realistic Networked Fires performance in FCS, in support of acquisition and design. This report discusses the 1st App cost, schedule, and performance baselines, the lessons learned from conduct of a distributed simulation of this magnitude, and some insights into the issues, questions, parameters, and results of the event.

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I. INTRODUCTION

In October 2002, the Research, Development and Engineering Command (RDECOM) was established by the Army Materiel Command (AMC) to integrate the research, development and engineering components of AMC subordinate commands. A Virtual Distributed Laboratory for Modeling and Simulation (VDLMS) was initiated and selected to execute the RDECOM's First Application (1^{st}App).

The objectives of 1^{st}App were to provide insights into the Networked Fires process and performance for Future Combat Systems (FCS), and to define the baseline capability of the VDLMS as it transitions towards the Modeling Architecture for Technology, Research. and EXperimentation (MATREX).

1^{st}App was designed as a distributed real-time simulation architecture utilizing established and emerging models and simulations at key RDECOM Modeling and Simulation (M&S) facilities, linked with representative test and user communities. Key analysis agencies also participated in experimental design and execution, but did not provide real-time M&S elements.

Geographic distribution of the event was accomplished by linking four simulation sites with one wide area network monitoring and collaboration server site, and physically bringing resources from the other VDLMS organizations to the four simulation sites, (Fig. 1) where green circles indicate distributed sites, tan circles indicate organizations not at own sites, and blue circles indicate personnel support only. Roles for these organizations are identified as follows:

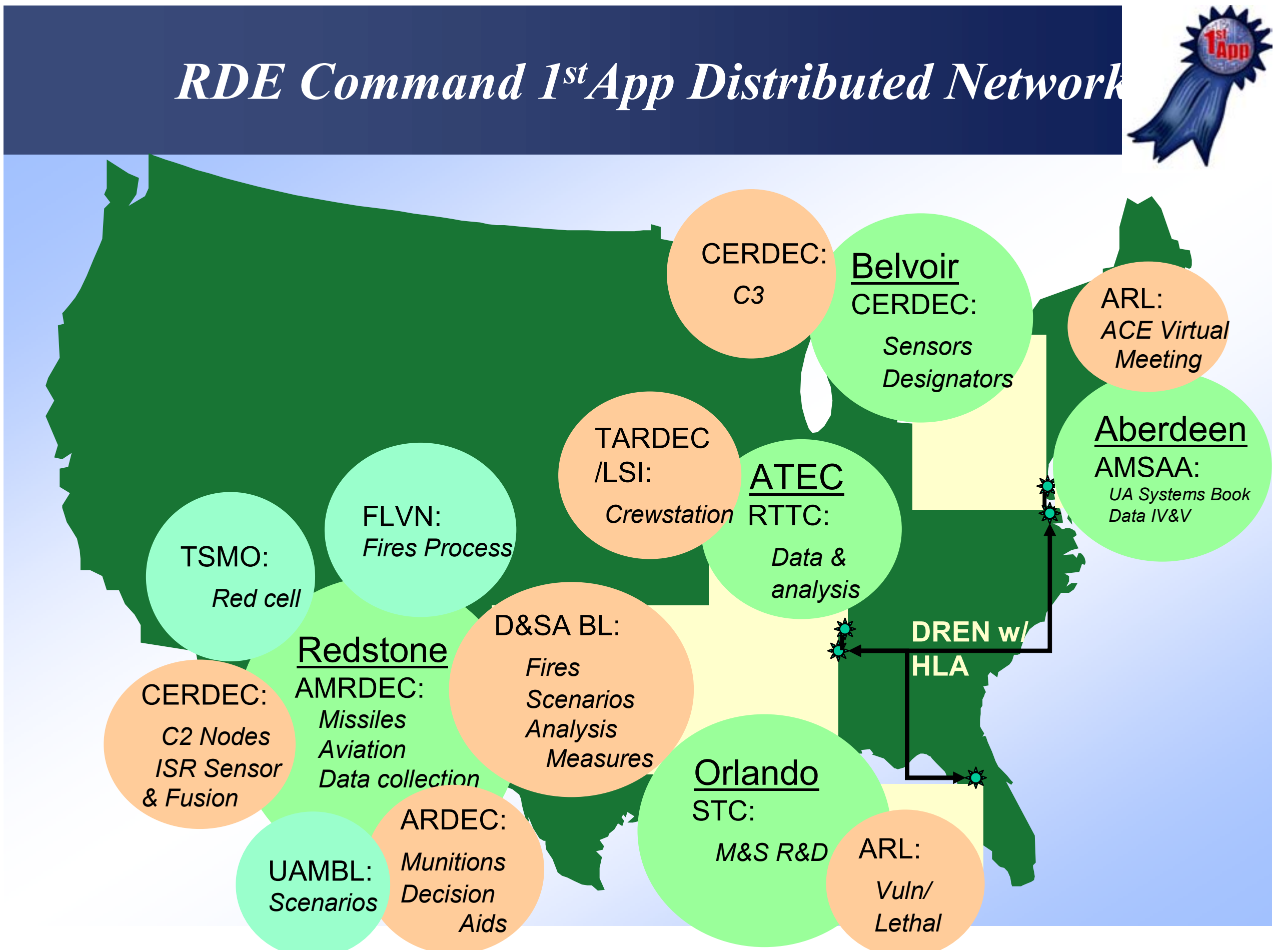

Figure 1. 1st App Distributed Network

1. Wide area network monitoring and collaboration server site:

- Defense Research and Engineering Network (DREN), Army Research Laboratory (ARL),
  Aberdeen Proving Ground, MD
  - Wide Area Network Support

2. Distributed Simulation Sites:

- Aviation and Missile Research, Development, and Engineering Center (RDEC) (AMRDEC), Redstone Arsenal, AL.
  - Aviation, Missile, and Unmanned Aerial Vehicle (UAV) Simulations
  - Networked Fires Technical Lead
  - Data Collection and Analysis Lead
  - Battlemaster

- RDECOM Simulation Technology Center (STC), Orlando, FL

- OneSAF Test Bed (OTB)
- Data Collection and Analysis Support

- Communications and Electronics RDEC, (CERDEC), Ft. Belvoir, VA
  - Reconnaissance, Surveillance, and Target Acquisition (RSTA) Suite
  - Unmanned Sensor Models
- Redstone Technical Test Center (RTTC), Redstone Arsenal, AL
  - Test Data Collection

3. Remote Site Organizations**:**

- Armaments RDEC (ARDEC) – (at AMRDEC)
  - Armaments and Munitions Models
  - Weapon/Target Pairing
- ARL – (at STC)
  - Vulnerability/Lethality
- Tank and Automotive RDEC (TARDEC) – (at RTTC)
  - Armed Reconnaissance Vehicle (ARV) Models
  - Vehicle and Mobility Models
- CERDEC Monmouth – (at AMRDEC and CERDEC Ft Belvoir)
  - Command, Control, Communications (C3)
  - Sensor Fusion
- Depth and Simultaneous Attack Battle Lab (D&SA BL) – (at AMRDEC)
  - Networked Fires Operational Lead
  - Networked Fires Models
  - Blue Force Roleplayers
  - Scenario Development and Approval

4. Coordinating Organizations:

- Army Materiel Systems Analysis Activity (AMSAA)
  - UA Systems Book
  - VV&A and Networked Fires Analysis
- TRADOC Analysis Command (TRAC) Ft Leavenworth (FLVN)
  - Networked Fires Process
- Threat Systems Management Office (TSMO)
  - Threat Roleplayers.
- Unit of Action Maneuver Battle Lab (UAMBL)
  - Scenario Development and Approval

II. ARCHITECTURE

1st App architectural design was based upon the requirement to utilize existing RDECOM facilities and simulations, which necessitated the physical backbone and simulation infrastructure to derive from those currently in use to support RDECOM customer experiments. A High Level Architecture (HLA) simulation backbone was laid across the physical connectivity to provide simulation interactions. Sub-networks of Distributed Interactive Simulation (DIS) traffic were bridged into the HLA architecture at three sites, then the appropriate HLA federates and DIS simulations were connected to provide the overall digital architecture.

In addition to the digital simulation network, 1st App also utilized digital collaborative environment tools and analog commercial voice conference calls to support experiment control and tactical voice communications. The entire architecture design is shown in Figure 2.

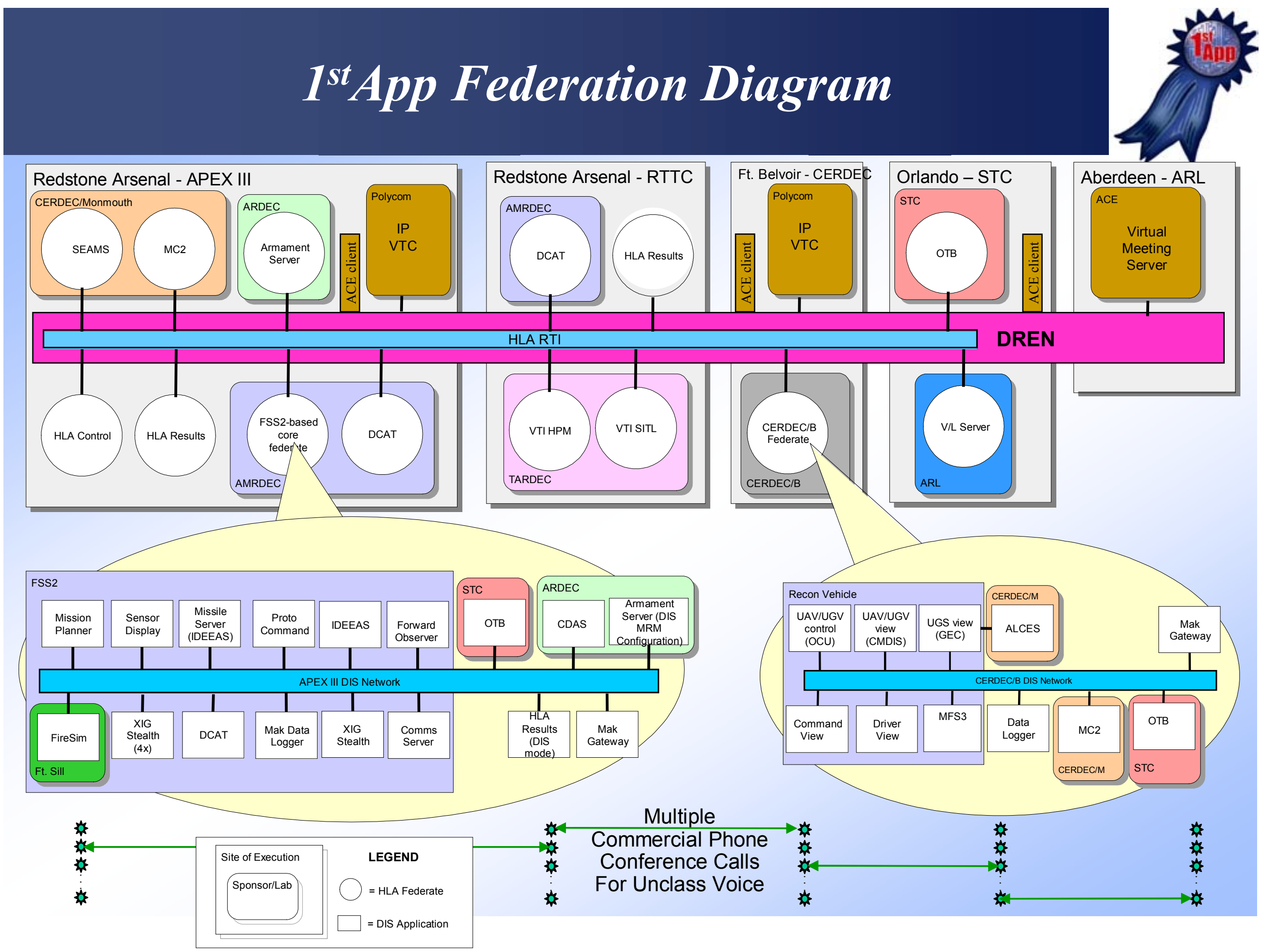

Figure 2. 1st App Federation Diagram

A. Wide Area Network (WAN) Architecture

The distributed simulation sites mentioned previously are all connected to the DREN, and have historically utilized the DREN to connect their real-time simulation capabilities, particularly in support of the RDEC Federation Calibration Experiment (CalEx) [1, 2].

A driving requirement for the physical architecture was classified operation. While encryption devices added complexity, they improved connectivity experienced during CalEx by allowing the network to bypass metropolitan area network firewalls and access control lists. A detailed discussion of the 1st App network design and performance is given in Reference 3.

B. Simulation Architecture

Most of the existing RDECOM simulations were developed using DIS protocols for interconnectivity, and have demonstrated compliance with HLA using the Real-time Platform Reference (RPR) Federation Object Model (FOM) and DIS/HLA gateways.

During CalEx, the RDEC Federation experimented with RPR FOM extensions to pass non-DIS compliant information, such as target acquisition truth data, and distributed data collection information. However, during the design of 1st App, it proved possible to configure all data exchanges into DIS compliant Protocol Data Units (PDUs) and corresponding RPR FOM data without the need for extensions. This allowed use of commercial DIS/HLA gateways without customization.

In addition to the gateway federates, there were several native HLA federates, also indicated in Figure 2. In order to control and limit WAN traffic and avoid feedback loops, only HLA traffic was allowed to pass across the WAN. Consequently, any DIS-to-DIS traffic between sites had to pass through two gateways to encode and decode data packets, which impacted performance in terms of data latency. This led to the addition of a small red cell at the CERDEC site to allow for local blue/red force interactions.

C. Experiment Control and Data Collection Tools

1st App utilized the Mak HLA Run-Time Infrastructure (RTI) and Mak gateways as commercial products. The RTI Execution (RTI Exec) process was run from the experimentation control and data collection cell at AMRDEC.

The commercial product “HLA Results” was used as the primary distributed data collection tool. HLA Results was run on several platforms to allow simultaneous data collection during runs, post-processing, and analysis queries.

1st App also utilized the AMRDEC-developed Data Collection and Analysis Tool (DCAT) for real-time monitoring of battlefield statistics. DCAT was originally developed for DIS, and was converted to an HLA interface in support of CalEx. Since the underlying data structures for DCAT are still DIS PDU based, it was closely aligned to RPR to support 1st App.

While DCAT focused on effects data, another run-time data collection tool was developed from a G2 rules-based engine, which provided real-time monitoring of target acquisition and fires process data, user selectable during the runs.

OTB and the Vulnerability/Lethality server were also used in data collection modes, even though those simulations are typically used as simulation truth data generators. Since OTB was not the primary scenario generator simulation for 1stApp, it was used to monitor battlefield entity status and enumerations to reduce risk for later use of OTB in MATREX events. Likewise, the Vulnerability/Lethality server will eventually be responsible for setting the damage states for MATREX entities, but for 1stApp, it was used to monitor state changes for verification purposes.

Other typical data collection and viewing tools such as plan view displays and stealth viewers were also used as needed.

D. Truth Data Simulations

1stApp was scoped to represent the quantities and types of systems composing an FCS UA, based on the UA Systems Book, using the then-current version 1.6 document.

The primary scenario engine for 1stApp, providing platform-level performance for the bulk of the red and blue forces, was the AMRDEC-developed Interactive Distributed Engineering Evaluation and Analysis Simulation (IDEEAS). IDEEAS is a constructive simulation which is synchronized with real-time to support virtual experimentation, with a low level of runtime user interactions. All entities in 1stApp were generated by IDEEAS, except as identified with the other models described.

FIRESIM from D&SA BL was used to represent all red and blue indirect fire platforms, with the exception of about half of the Non Line-of-Sight Launch System (NLOS LS) platforms which are otherwise represented by the NLOS LS Mission Management Applications (MMAs). FIRESIM was also utilized to represent all counter-battery radar systems.

OTB represented a small number of air sensor platforms used to populate fused sensor data. OTB also represented the local red ground force at CERDEC for interaction with RSTA simulations.

When launch platforms fired missiles and armaments, the flights, interactions, and detonations of those entities were generated by the Missile Server from AMRDEC and the Armament Servers from ARDEC.

The TARDEC manned simulator and Human Performance Model (HPM) represented two RSTA vehicles, which controlled ARV's. The CERDEC manned simulator suite represented a single RSTA vehicle, which also controlled a Class I UAV, a Small Unmanned Ground Vehicle (SUGV), an Unattended Ground Sensor (UGS) suite, and an Intelligent Munition System (IMS). There were also several desktop simulators of Class I-IV UAV's, and dismounted forward observers at AMRDEC.

E. Perceived Data Simulations

C3 functionality was focused on those functions critical to Networked Fires, which included target reporting, sensor fusion, situational awareness, weapon-target pairing, calls for fire, fire missions, and Battle Damage Assessment (BDA).

Communications representations were limited to two key areas: communications between ground sensor suites and the RSTA vehicle, which were simulated by the CERDEC ALCES model, and communications between NLOS LS missiles and their control stations and relays, which were simulated by the AMRDEC Comms Server.

Many of the existing tools from the RDECOM organizations had overlapping functionality in Command and Control (C2), so the challenge was to scope meaningful roles for these simulations so that fire missions could be executed at various levels of command. Collectively, these products provided the functionality of a Network-Centric system without explicitly modeling the individual nodes and interfaces of that system.

Mission threads were represented as follows:

Sensor reports from various RSTA assets were sent to the CERDEC Sensor Exploitation and Management System (SEAMS) simulation for fusion and forwarding to assets including the Mobile Command and Control (MC2) system and Protocommand. Other sensings were sent directly into the network systems without the fusion function occurring.

MC2 then updated situational awareness, and Protocommand utilized an automated Attack Guidance Matrix (AGM) and the dynamic organizational allocation of fires to determine weapon-target pairings. MC2 also sent target information to FIRESIM for processing.

From Protocommand and FIRESIM, fire requests were issued, either directly to firing platforms or for further allocation to the ARDEC Combat Decision Aiding System (CDAS), depending on which echelon of command was executing the fires.

For fires allocated to the NLOS LS system, depending on which batteries were assigned, FIRESIM or the NLOS LS MMA's determined the weapon flight paths and executed the fires.

III. METRICS

The two 1stApp objectives, stated as issues, were as follows:

1. Issue 1.0: Defining the performance of the legacy M&S architecture as a baseline for VDLMS.

2. Issue 2.0: Matching tactics to physics to produce a realistic expectation of Networked Fires performance in FCS.

Two sets of metrics were developed, corresponding to these two 1stApp objectives. These metrics were defined in a dendritic structure, beginning with the objectives as top-level issues, decomposing the issues into sub-issues, sub-issues into Essential Elements of Analysis (EEAs), EEAs into Measures of Effectiveness (MoEs), and MoEs into Data Requirements. These data requirements were used to drive the data collection, reduction, and analysis requirements for the event.

Following are the sub-issues and EEAs for both objectives:

1. Sub-issue 1.1: Defining the cost of execution of the legacy M&S architecture as a baseline for VDLMS.
   EEA 1.1.1: Actual cost of execution of the 1stApp architecture as configured to represent FCS Networked Fires.

2. Sub-issue 1.2: Defining the schedule of execution of the legacy M&S architecture as a baseline for VDLMS.
   EEA 1.2.1: Actual schedule of execution of the 1stApp architecture as configured
   represent FCS Networked Fires.

3. Sub-issue 1.3: Defining the technical performance of the legacy M&S architecture as a
   baseline for VDLMS.
   EEA 1.3.1: Actual performance of the 1stApp architecture as configured to representFCS Networked Fires.

4. Sub-issue 2.1: Matching tactics to physics for the Sensor component to produce a realistic expectation of Networked Fires performance in FCS.
   EEA 2.1.1: Roles of sensors to support targeting
   EEA 2.1.2: Mix and quantities of sensors to provide sufficient and dynamic threat coverage for fires
   EEA 2.1.3: Roles of sensors to support BDA.

5. Sub-issue 2.2: Matching tactics to physics for the Battle Command Component to produce a realistic expectation of Networked Fires performance in FCS.
   EEA 2.2.1: Control measures needed to execute fires
   EEA 2.2.2: Role the CROP plays in fires processes.

EEA 2.2.3: Ability to perform dynamic sensor management
EEA 2.2.4: Comms performance/limits for selected arcs
EEA 2.2.5: Effectiveness of decision aids and pre-planned fires
EEA 2.2.6: Ability to perform dynamic redirection and massing of fires
EEA 2.2.7: Sensor/shooter timelines and latencies
EEA 2.2.8: Degree of automation of fires execution.

6. Sub-issue 2.3: Matching tactics to physics for the Effects Component to produce a realistic expectation of Networked Fires performance in FCS.
   EEA 2.3.1: Ability of precision munitions to acquire targets
   EEA 2.3.2: Ability of munitions to hit targets and produce damage
   EEA 2.3.3: Fire mission service and success rates
   EEA 2.3.4: Effectiveness of various firing protocols
   EEA 2.3.5: Effectiveness of munition/target selections
   EEA 2.3.6: Sufficiency of basic loads to support defined missions.

In the interest of space, the entire list of MOEs and Data Requirements are not included in this report, but are part of the 1stApp Final Report [4].

IV. RESULTS

Results are broken out based on the two 1stApp objectives. These results have produced a number of insights and lessons learned, many of which are more fully documented in Reference 5.

A. VDLMS M&S Baseline

VDLMS baseline metrics were identified for cost, schedule, and performance.

1stApp costs include those funded directly by the VDLMS STO, funds supporting the underlying NLOS LS Full Scale Simulation (FSS), and funds provided by individual RDECOM organizations. While the VDLMS STO allocated $3.5M to execute 1stApp, this amount was more than matched by the other two categories, to provide a total of approximately $8.0M.

The 1stApp completion date was fixed due to availability of D&SA BL personnel, and the requirement to conclude prior to the FCS Milestone B decision. The schedule included two weeks of record runs and one week of VIP briefings, as is shown in Figure 3. Given the fixed schedule endpoint, length of time to gain approval for classified operation, and the late arrival of funds, the distributed site integration time was delayed by one month from the original plan.

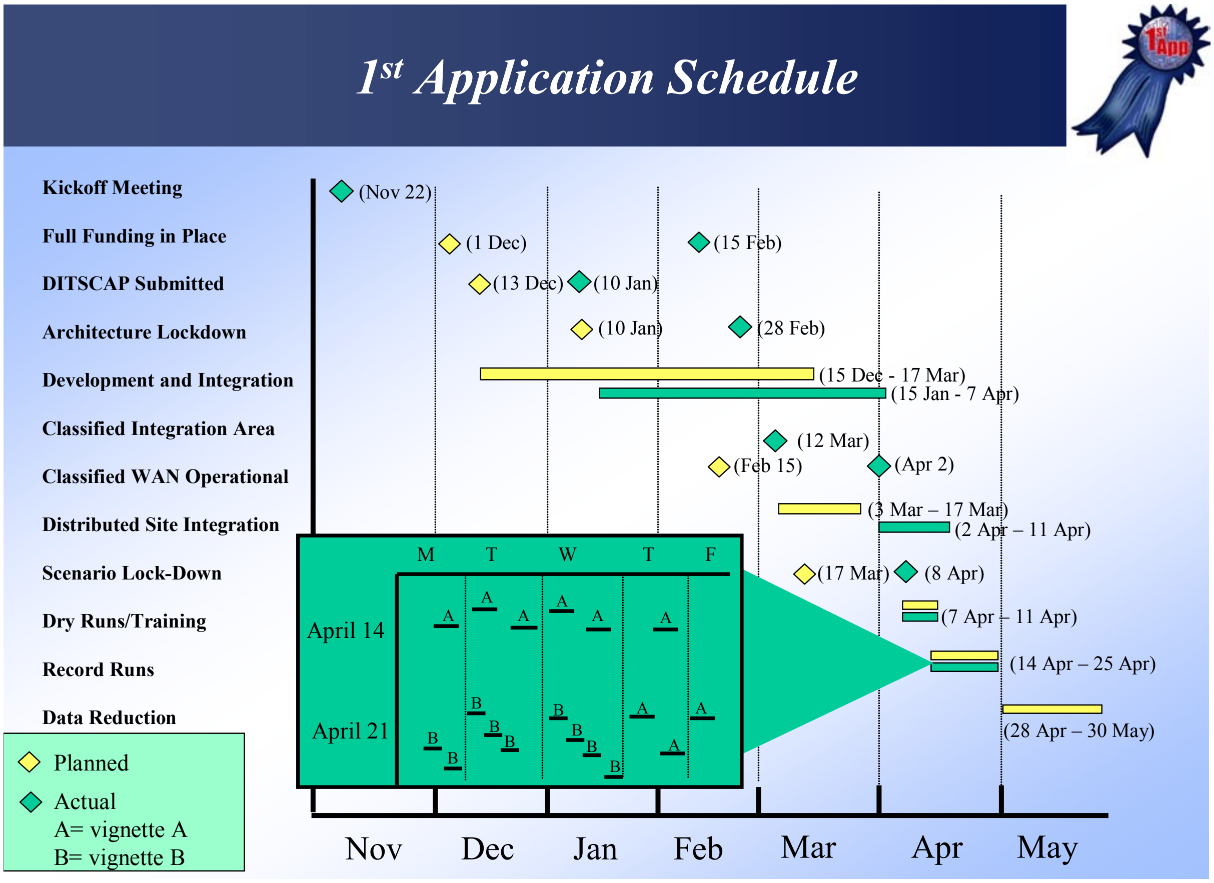

Figure 3. 1st App Schedule

The VDLMS performance results from 1stApp are based upon the size of the scenario, the complexity of the federation, the number of successful record runs, and statistics regarding network and HLA performance.

The maximum size of the FCS UA slice represented within stable simulation runtime was for Vignette A, consisting of one entire UA less two maneuver battalions, plus two NLOS batteries from adjacent UA's, and two High Mobility Artillery Rocket System (HIMARS) batteries and two Q47 radars from the Unit of Employment (UE). Vignette A runs executed over the course of approximately 3 hours, and peaked at roughly 2500 entities, including munitions in flight. Each of these runs produced two million PDU's, logger files of 450MB, and 1.3GB HLA Results database files. Vignette B was a 1-hour slice of Vignette A, scaled down to about 500 entities. These runs each produced 300,000 PDU's, 55MB logger files, and 500MB HLA Results databases.

Eighteen successful record runs were completed over the 2-week run period, broken out by vignette as shown in Figure 3. (In addition, Vignette B was run for five iterations during VIP demonstrations). The 18 record runs were out of a total of 21 attempts. For each record run, outstanding simulation problem reports were documented to ensure that the proper analytical insights could be drawn from each run. Since final integration completion overlapped the first

few record runs, the later runs tended to be more robust than the earlier ones in terms of analytical validity. Along with the freeplay of the 1stApp roleplayers, this gave each run a unique personality which lent its utility towards addressing the various networked fires metrics. The total stable runtime to execute these 18 record runs was approximately 40 hours.

Network latencies for the 1stApp WAN ranged from 2ms to 36ms based on ping tests between sites across the DREN. Throughput losses ranged from 0 percent with 18Mb connections to 0.29 percent with 4Mb connections, measured from each site, with AMRDEC as the server. Bandwidth usage, measured at AMRDEC, was as shown in the Table.

Table. Bandwidth Utilization

Vignette A	Average	Maximum
DIS	0.37Mb/s	9.67Mb/s
HLA	0.13Mb/s	2.67Mb/s
Vignette B	Average	Maximum
DIS	0.00Mb/s	2.84Mb/s
HLA	0.02Mb/s	1.43Mb/s

Performance for the simulation layer proved to be very stable and robust. The Mak RTI and Gateway demonstrated high reliability and stability. Joining and resigning the federation took under two minutes as a rule. The HLA Control tool allowed the federation to monitor object updates to assist in federation management.

The Mak RTI Exec Graphical User Interface (GUI) did cause a problem with joining and rejoining, requiring federates which dropped out of the simulation to change their names before rejoining. This bug was avoided through the use of the RTI Exec from the command line interface. The RTI Spy was also disabled for similar reasons.

Other issues in simulation layer performance were predominantly in the areas of federation configuration, gateway configuration, and gateway latencies. Most of the gateway latency was reduced through fine tuning the configuration file settings, but significant latencies were experienced between simulations on separate DIS networks, when traffic had to go through two gateways.

Individual performance issues were identified for individual federates. Those issues are fully documented in the 1stApp simulation problem report database.

B. Networked Fires Performance

Networked fires performance fell into two categories; the general performance mapping to the EEAs shown above, and the specific performance of the NLOS LS system as was addressed in the underlying FSS experiment. Detailed NLOS LS metrics and results can be found in Reference 4. General NLOS LS observations are as follows:

- A key observation was the dominant influence of ISR and targeting processes upon terminal acquisition, which depends upon getting the footprint of the missile seeker over the target.

- The representative NLOS-LS subnet sustained the load imposed by the chiplet-based imagery downlink with minimal (<1s) latencies.

- The peak load on the NLOS-LS subnet was approximately 2.8 Mb/s, with an observed sustained load of approximately 614 kb/s.

- The load imposed on the NLOS-LS network was driven by the instantaneous number and type of reporting missiles in flight (approximately 70 Loitering Attack Missiles (LAM) and 20 Precision Attack Missiles (PAM)) and waveform compatible relays. (These performance numbers reflect a 10:1 compression ratio for the downlinked imagery, and sufficient data buffers on each relay).

- Full-LADAR-swath imagery downlink from LAM can be supported if used judiciously.

- Frequent Health and Status messages imposed minimal network burden. The NLOS-LS subnet load was much more sensitive to target density than node count.

- The prototype Mission Management Applications (surrogates for the FCS objective C2) were user-intensive, effectively limiting the number of active NLOS-LS missions.

- Common control measures, grid reference and symbology between all command and control applications are required for synchronized effects.

- The LAM exhibited limited Battle Damage Assessment capability, but filled a reconnaissance and surveillance role as a stop-gap measure.

- Forward sensors (UAV and armed reconnaissance helicopters) were key contributors to the NLOS-LS fight.

For the general networked fires performance, the EEAs and MoEs were translated by AMSAA into a set of eight analysis questions. Comprehensive analytical answers to these questions will be addressed in a forthcoming AMSAA technical report, but particular insights for each question are offered as follows:

- Question 1: Did the missile network impact the ability to command and control both the LAM and PAM? - The "missile network," in this context, refers to the radio network, nodes, relays, and control stations that are part of the NLOS LS system, as opposed to the more general FCS net-centric system to execute networked fires. While this question is addressed in more detail by the FSS effort, in general, 1stApp demonstrated that the missile network was sufficiently robust, including the necessary radio bandwidth, for the command and control of LAM and PAM to not be negatively impacted, even with imagery being passed back to the control stations. 1stApp demonstrated adequate functionality and bandwidth to support redirection and changes in missions and waypoints for LAMs in flight, as well as target updates for PAM.

- Question 2: How hard is it for an operator to control the LAM ? This question is specifically addressed by the functionality of two federates: FIRESIM and the NLOS LS MMA. Both use plan view displays to insert waypoints, select loiter regions, and retask missiles in flight. Both of these applications have their strengths and weaknesses, but both provided sufficient control for LAM as surrogates for a definitive operator interface, and as prototypes for the tactical solution. Difficulty of operator control would be considered low, based on the fact that 1stApp was able to execute all LAM missions requested, and produced repeated peaks of up to seventy-five LAMs in flight.

- Question 3: How is the information displayed on the various Common Operational Picture (COP) displays used? Answering this question is complicated by the fact that 1stApp utilized several simulations with overlapping functionality rather than representing a true COP. However, collectively, the COP information was successfully used for situational awareness, weapon-target pairing, fire mission planning, and all other functions required to execute networked fires.

- Question 4: What are the time lines and latencies between major segments of the engagement process? Detailed timelines were produced from 1stApp, but in the interest of space, are not addressed here.

- Question 5: What is the impact of the sensor coverage on mission effectiveness? Sensor coverage seemed sufficient for mission effectiveness, but there were limitations on the ability of Class II UAVs to adequately acquire targets based on flight profiles coupled with sensor performance, and a simulation limitation in retasking the IDEEAS UAVs which limited the ability to dynamically adapt sensor coverage for all missions.

- Question 6: How effective were the COP display systems in portraying BDA? During the record runs, several different methodologies were explored to highlight targets with known damage, and targets that had been engaged. A very interesting process was established to cross-reference MTI reports with Counter-Mortar Counter-Battery (CMCB) radar to determine shoot-and-scoot behaviors to infer BDA. Other BDA sensing was limited due to the resolution of target model visual representations.

- Question 7: How well did the networked fires reduce the threat force? In both 1stApp vignettes, the blue force decimated the red force. Actual attrition data is not available in unclassified form.

- Question 8: What was the munitions expenditure rate? Munitions expenditures were explicitly accounted, but in the interest of space, are not discussed here.

V. CONCLUSIONS

With the successful execution of 18 record runs of a significant slice of an FCS UA, 1stApp met its success criteria and demonstrated that current RDECOM simulation resources and tools are relevant to FCS and the OF, and sufficient to answer a number of analytical questions. It also demonstrated a performance baseline to ground the emerging MATREX architecture as the community evolves to be able to address engineering and technical issues in UA and UE contexts.

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